EVALUATION OF AN INSTRUMENT TO DETECT PRESENCE, SIZE AND DEPTH OF STEEL EMBEDDED IN PORTLAND-CEMENT CONCRETE

by

K. L. Saucier

November 1965
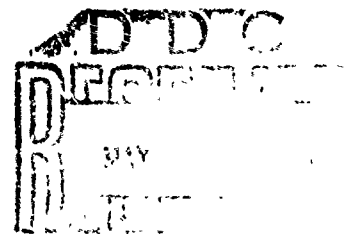
Sponsored by

Office, Chief of Engineers

U. S. Army

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

20

Foreword

This investigation was authorized by the Office, C' .ef of Engineers, as part of the Engineering Studies Item ES 622, "Invest .tion of Testing Methods and Apparatus."

The investigation was conducted during 1964-1965   the Concrete Division, U. S. Army Engineer Waterways Experiment S .t .n, under the direction of Messrs. Thomas B. Kennedy, Bryant Mather. .ames M. Polatty, and William O. Tynes. Mr. K. L. Saucier participate' in the investigation and prepared this report.

Directors of the Waterways Experiment Station during the conduct of this study and the preparation of this report were Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

iii

Contents

Summary

Two portable, lightweight instruments, operating on the principle of comparing the fixed electromagnetic characteristics of a reference transformer with the variable ones of a measured transformer, were evaluated for ability to locate and identify reinforcing steel in reinforced concrete. One instrument was found to be capable of approximately (a) locating reinforcing rods, (b) identifying rods up to 1 in. in diameter with a maximum cover of 2 in., and (c) determining thickness of concrete cover to an accuracy of 1/4 in. for coverings up to 4 in. The second instrument, discussed in Appendix A, was found capable of approximately locating reinforcing rods and determining concrete coverage to an accuracy of 1/4 in. for coverings up to 3 in.

EVALUATION OF AN INSTRUMENT TO DETECT PRESENCE, SIZE, AND DEPTH OF STEEL EMBEDDED IN PORTLAND-CEMENT CONCRETE

Background

1. A simple, compact instrument or tool which could be used to determine the location, orientation, size, and depth of reinforcing steel or other ferrous metal objects embedded in portland-cement concrete would find many applications in concrete construction and investigational work. In the past it has been necessary to either remove the concrete cover over such objects or use radiation-sensing systems such as X-rays or magnetic flux devices. Removing concrete is usually undesirably damaging to the structure, especially if extensive or critical areas are to be investigated. The X-ray and magnetic flux methods have no damaging effect on the concrete but are slow and costly.

2. When the U. S. Army Engineer District, Washington, D. C.,* needed a method for verifying the presence or absence of reinforcing steel in a reinforced concrete multistory structure, a metal locator which had been developed as an aid to surgeons in the detection of metallic objects in human bodies was suggested.** The metal locator is an electronic device, using a thin pointed probe for the detection and location of foreign metal objects. A meter and loud speaker are synchronized so that a sound is obtained when the probe is in proximity to metal. The probe is then moved to lightly scan the concrete surface in order to locate and approximately identify the reinforcing rods. However, with this equipment it is not possible to distinguish between rods of different sizes unless they are located at the same depth in the concrete. It is, therefore, most desirable for the operator of the equipment to be thoroughly familiar with the intended spacing of reinforcement, both vertically and horizontally, and the size of the steel in the structure prior to the investigation. In contrast to the metal locator, the device with which the study reported herein was concerned has been advertised as possessing

---

* Redesignated Washington Area Office in July 1961.

** W. M. Jaillite, "Locating metal embedded in concrete," Proceedings, American Concrete Institute, vol 29, No. 8 (February 1933), pp 705-707.

the capability of measuring the thickness of concrete covering and determining the rod diameter within certain limits.

Purpose and Scope

3. The purpose of this investigation was to evaluate a device for locating and identifying reinforcing steel in hardened concrete.

4. Panels and blocks made from a conventional 3000-psi concrete mixture (limestone coarse aggregate and natural sand fine aggregate) were molded with deformed reinforcing rods of various sizes embedded at several depths in the concrete. Tests were made to determine if the device could be used to locate and identify the reinforcing rods. Fig. 1 is a photograph of the test specimens.

Apparatus

5. The device studied, designated instrument A,* is shown in fig. 2. The principle of operation as stated by the manufacturer is based on the method of "comparing the fixed electromagnetic characteristics of a reference transformer with the variable ones of a measured transformer (probe). The indicating means is a specially calibrated galvanometer." The instrument operates on six commercial 1.5-volt (flashlight) batteries and costs approximately $400. The manufacturer's literature stated that the device "permits measurements up to a maximum covering of 4-3/4 in." However, the operating instructions received with the instrument contained reference charts which the manufacturer stated "apply to the most common steel quantities having a tensile strength of approximately 80,000 psi with a concrete covering of 1.4 to 2.4 in."

Procedure

6. The following instructions were given in the calibration and operation manual for the device.

---

* A somewhat similar apparatus, designated instrument B, was evaluated subsequent to the completion of tests on instrument A. An evaluation of instrument B is discussed in Appendix A.
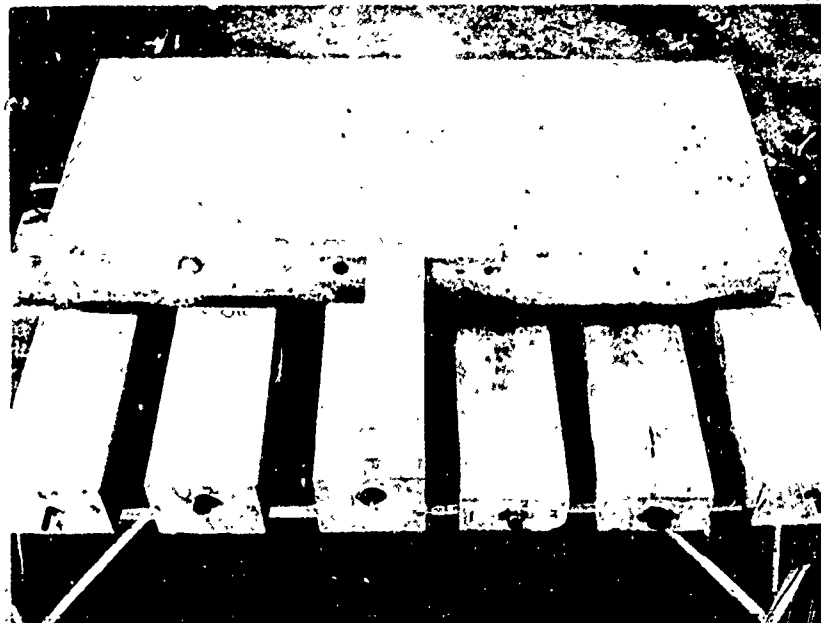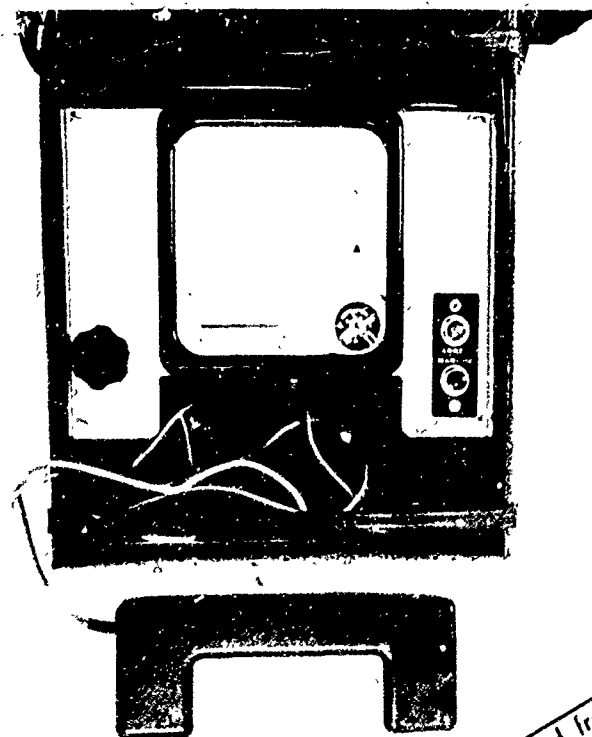
Fig. 1. Test specimens

Fig. 2. Instrument A, probe, and spacer

a. Calibration. To calibrate the device a wooden spacer and steel bar, as shown in fig. 3, had to be fabricated locally. Two checks were specified in the instructions as follows:

(1) Zero-point of galvanometer. If the galvanometer pointer does not move to zero when a slow magnetic short circuit is applied, adjustment to zero is effected by use of a rheostat.

(2) Air gap of transformer. If the galvanometer needle does not deflect a specified amount when the test block is placed over the probe as shown in fig. 3, a recalibrating screw on the reference transformer is used to make necessary adjustments.
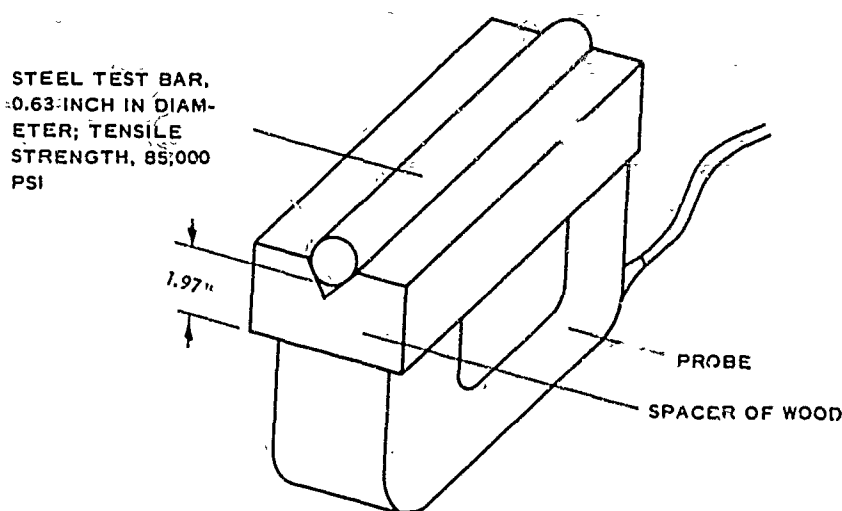
STEEL TEST BAR, 0.63-INCH IN DIAMETER; TENSILE STRENGTH, 85,000 PSI

1.97"

PROBE

SPACER OF WOOD

Fig. 3. Spacer and test bar

b. Location of reinforcing steel. Location and direction of the individual steel reinforcing elements are determined by systematically scanning the surface of the concrete being tested with the probe. When the probe approaches a reinforcing rod, the pointer is deflected from its original reading of 90 on the outermost scale of the galvanometer dial. The probe is then moved so as to parallel the steel until the pointer deflection reaches a maximum, i.e. until a minimum numerical reading is shown on the outermost scale (90 graduations total). A graphic representation of this action is given in figs. 4a and 4b.

c. Determination of rod diameter. After the location of a reinforcing rod is determined, the rod's diameter can be determined in the following manner. The probe is placed in a position where there is no interference from surroundings, and the pointer of the galvanometer is set to the zero position with the adjustment knob. The probe is then placed directly above the rod axis on the concrete surface at
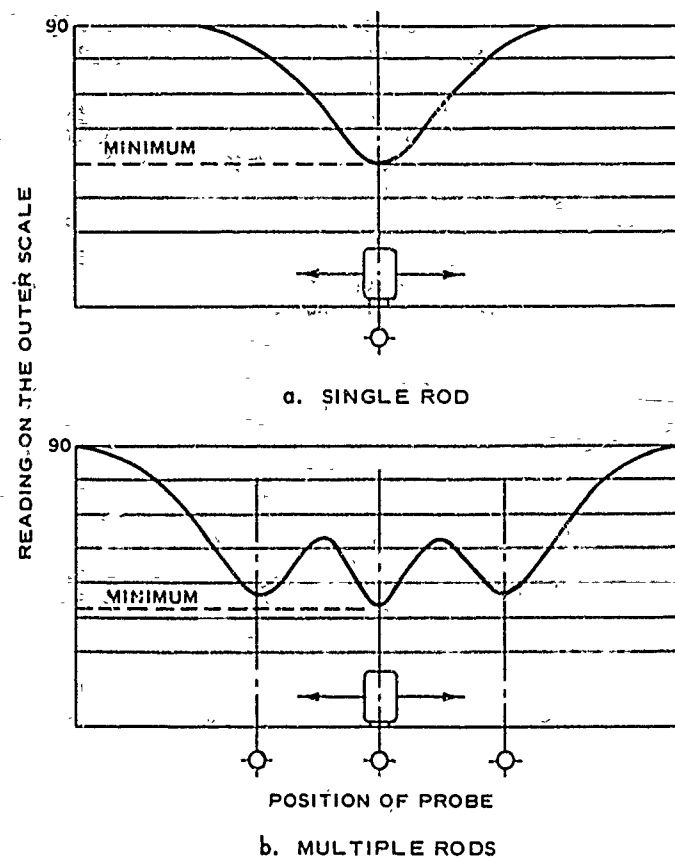
4

Fig. 4. Graphic representation
of location procedure

determined by the method given in paragraph 6b. The pointer
deflection, N_1, is read from the outermost scale. The probe
is removed, the spacer (see fig. 2, page 3) set in place, and
the pointer again set to the zero position. A second measure-
ment is made at exactly the same point with the spacer under
the probe. The pointer deflection, N_2, is read from the outer-
most scale. The rod diameter is determined from a chart such
as shown in fig. 5, in which $\Delta N = N_2 - N_1$ is plotted as a
function of N_1.

d. Measurement of the thickness of concrete covering. The thick-
ness of concrete covering is determined from the rod diameter
and auxiliary curves on the face of the instrument. The probe
without the spacer is placed directly over and aligned with
the rod. The point of intersection of the pointer with a
curve representing the known rod diameter is noted. Using
this point the amount of cover present is determined by
interpolating between secondary curves on the galvanometer
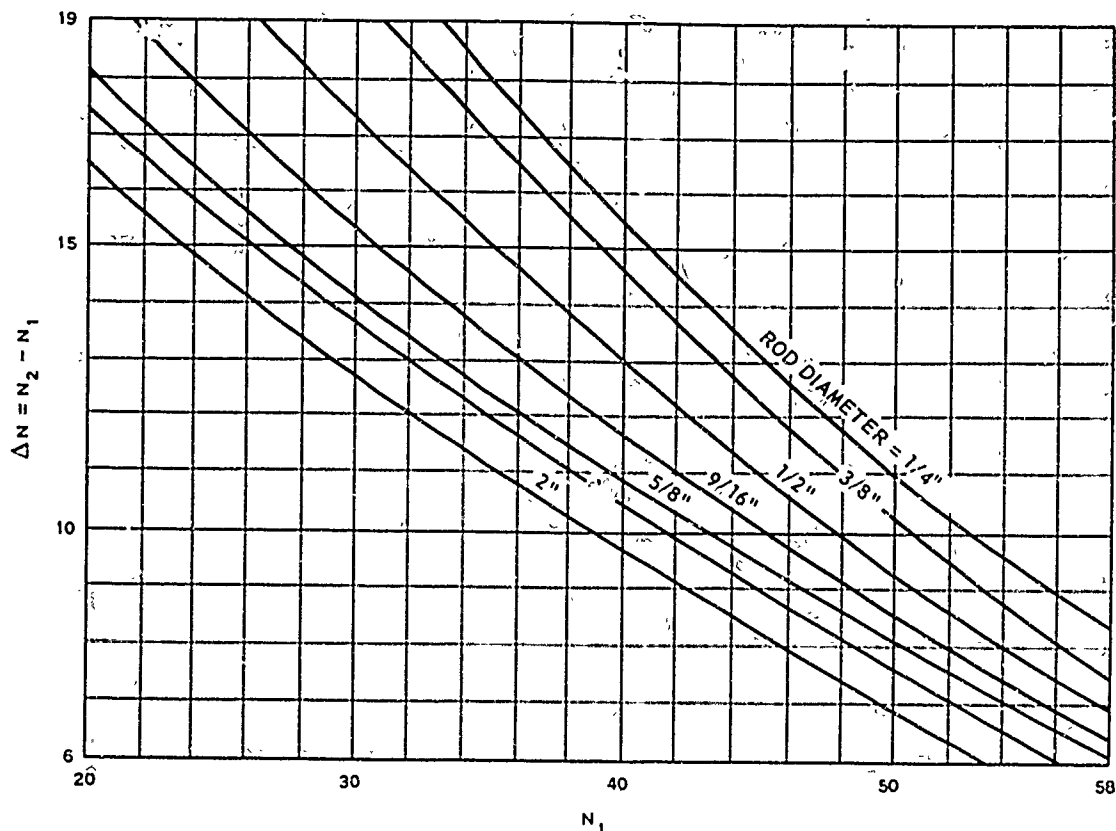scale. An alternate method of determining concrete cover is

5

Fig. 5. Chart for determining rod diameter

as follows. At the point where the covering is to be
measured, the maximum deflection on the outer scale of the
galvanometer is noted. A second measurement is made at the
corresponding point of an exactly copied uncovered reinforce-
ment system in such a way that nonmagnetic spacers (wood,
cardboard, plastic) are interposed between probe and rein-
forcement until the pointer deflection corresponds to that of
the first measurement. The total thickness of spacers
inserted corresponds to the effective concrete covering at the
first measurement point of the structural component. It is
most important to check and set, if necessary, the zero posi-
tion of the pointer before each reading is made.

e. Identification of groups of rods. If it is determined that
reinforcing rods are spaced closer than 4 in. on centers, a
correction factor must be applied. The spacing is first deter-
mined, and then a rod diameter is tentatively identified by the
method described in paragraph 6c. Using a chart supplied with
the apparatus, a correction factor is applied to the spacing
and tentative rod size, which yields the correct rod size for
the group.

f. Quality check of steel rods. The operating instructions state
that the indication of the instrument (assuming the diameter
of the rod is known) is "not only a function of the distance

6

between the probe and rod but to a lesser degree it also
depends on the quality of the material of the rod. Such
(quality) tests are to be carried out in the retrorange
of the galvanometer where the sensitivity of the appli-
ance is much greater." The following procedure is given
for a quality check of reinforcing rods: (1) procure a rod
with exactly the same diameter and manufactured by the same
process as the rods to be tested; (2) determine the quality
of this rod unequivocally; (3) fabricate a nonmagnetic
spacer of the thickness required to bring pointer in retro-
range of galvanometer; (4) place the probe together with
the spacer on comparative rod and note the pointer deflec-
tion; and (5) scan the test rods in the same manner, noting
deflection. Test rods which yield greater numerical de-
flection readings (i.e. toward the delta mark on the
galvanometer dial) are inferior to the comparative rod.

Tests and Results

7. Concrete blocks were cast with Nos. 3, 4, 8, and 10 deformed
reinforcing rods embedded at several depths. The instrument was first
calibrated according to the procedure outlined in paragraph 6a. Results
of tests made to locate and identify the rods are given in the following
paragraphs.

Location

8. It was discovered that location of reinforcing rods could be
determined by following the procedure given in paragraph 6b and that the
instrument pointer did, indeed, deflect as shown graphically (fig. 4,
page 5) for single rods and multiple rods spaced over 2 in. apart. However,
where several rods were involved, if the spacing between rods was less than
2 in. the graphic representation obtained was as shown for single rods, it
therefore appears to be difficult to define the reinforcement system with
the instrument tested in this study when rods are spaced at intervals of 2
in. or less. It should be noted at this point that common sense and judg-
ment will greatly assist in any evaluation with this device. For example,
quite often the operator will be able to determine the direction in which
the reinforcing bars are laid, and this will facilitate determining the
spacing with the instrument. For a concrete covering of 4-1/2 in., the
minimum numerical deflection readings (see graphic representation,
fig. 4, page 5) experienced with Nos. 3, 4, 8, and 10 bars were 87, 86, 85,

and 83, respectively. Since the maximum figure on the scale is 90, it would not be feasible to locate with confidence rods embedded at depths greater than 4-1/2 in.

Determination of rod diameter

9. Two readings, N_1 without the spacer and N_2 with the spacer, were made using the procedure described in paragraph 6c and several test conditions to determine if the device could be used to determine the size of reinforcing rods. Results are given below:

Rod Size, in.	Concrete Cover, in.	N_1	N_2	ΔN (i.e. $N_2 - N_1$)	Indicated Rod Size, in. (from fig. 5, page 6)
None	4-1/2	90	90	0	*
3/8	7/8**	38	53	15	3/8 (+)
3/8	1-3/4	55	64	9	1/4 (+)
3/8	2-1/2	75	78	3	*
3/8	3-1/4	83	83	0	*
1/2	1-1/2	27	43	16	9/16 (+)
1/2	2-1/8	56	66	10	1/4 (-)
1/2	2-5/8	73	78	5	*
1/2	3-1/2	85	85	0	*
1	1**	38	49	11	1
1	2	40	50	10	1 (+)
1	2-1/2	65	70	5	*
1	3	76	78	2	*
1-3/8	1**	26	39	13	2 (+)
1-3/8	2	33	45	12	1 (+)
1-3/8	2-1/4	45	55	10	9/16
1-3/8	2-1/2	54	61	7	5/8
1-3/8	3-1/4	74	78	4	*
1-3/8	4	82	82	0	*

---

* No determinations possible; ΔN off scale on identification chart (fig. 5, page 6).

** Inert spacer (7/8-in. thick) required to bring instrument within range.

The results indicate that the instrument approximately identified the 3/8-in. rod at 7/8- and 1-3/4 in. cover, the 1/2-in. rod at 1-1/2- and 2-1/8-in. cover, and the 1-in. rod at 1- and 2-in. cover. However, erratic results were obtained on all other measurements for these rod sizes and on all measurements of the 1-3/8-in. rod. It should be noted here that the range of the band for 1- to 2-in. size rods (see fig. 5, page 6) is extremely limited. Obviously, correct identification in the 1- to 2-in. range would be extremely difficult with this chart. In the tabulation, the readings marked with a double asterisk required the use of an additional nonmetallic spacer to bring the galvanometer on scale. Apparently a minimum effective spacing of approximately 1-1/2 in. to the steel is required for operation. However, this should present no problem since the thickness of the inert spacer can be deducted from the indicated cover to obtain the actual cover.

10. The operating instructions specified a calibration procedure using steel with a tensile strength of approximately 80,000 psi. To determine what effect steel strength would have on identification of rods, two 5/8-in.-diameter rods were placed under 1-3/4 in. of simulated concrete cover. A 68,000-psi rod gave an indicated size of 9/16 in. under an indicated concrete coverage of 1-5/8 in. An 85,000-psi rod used in the original calibration gave an indicated size of 1/2 in. under an indicated concrete coverage of 1-3/4 in. Since the rod diameter determinations are, at best, approximations, it would appear that differences in ultimate strength would be lost in variations within the tests for determination of rod size. However, it would appear logical to select a calibration rod with properties approximately the same as those of the rods in the concrete under test. Specific tests for quality check of steel rods are carried out in the retro-range of the instrument as indicated in paragraphs 6f and 13.

Thickness of concrete covering

11. As noted in paragraph 6d, the thickness of the concrete covering is determined from auxiliary curves on the face of the instrument after the rod diameter has been determined. Given below are results of tests with several thicknesses of concrete cover.

| Concrete Cover, in. | | Actual Rod | |
Indicated*	Actual	Size, in.	Remarks
0	0	0	No reinforcement
3/4	7/8	3/8	5/8-in. spacer
1	1	1	7/8-in. spacer
7/8	1	1-3/8	7/8-in. spacer
1-3/8	1-1/2	1/2	--
1-5/8	1-3/4	3/8	--
1-7/8	2	1	--
1-3/4	2	1-3/8	--
1-7/8	2-1/8	1/2	--
2	2-1/4	1-3/8	--
2-1/4	2-1/2	3/8	--
2-1/2	2-1/2	1	--
2-1/4	2-1/2	1-3/8	--
2-3/8	2-5/8	1/2	--
3	3	1	--
2-3/4	3-1/4	3/8	--
3	3-1/4	1-3/8	--
3-1/2	3-1/2	1/2	--
3-3/4	4	1-3/8	--

* Using the auxiliary curves with the actual rod sizes.

Indications are that if the rod diameter is known, either a priori or from previous test, the thickness of concrete covering can be approximately determined to an accuracy of 1/4 in. for coverings up to 4 in. It should be remembered, however, that tests (paragraphs 9 and 10) indicate that the rod size can be determined only approximately and only for concrete coverings of up to 2 in. and rod sizes of up to 1 in.

Identification of rods in groups

12. Tests utilizing 3/8-in. rods under 1-3/4-in. concrete cover were made for several rod spacings as given below:

Number of Rods	Spacing Between Rods, in.	Tentative Rod Size, in.	Correction Factor	Indicated Rod Size, in.
2	1	5/8	1/2	5/16
2	3	1/2	2/3	1/3

(Continued)

10

Number of Rods	Spacing Between Rods, in.	Tentative Rod Size, in.	Correction Factor	Indicated Rod Size, in.
2	5	3/8	1	3/8
3	1.5	2	1/3	2/3
3	2.5	5/8	1/2	5/16
3	3.5	5/8	2/3	5/12

The indicated rod size varied from 5/16 (0.31 in.) to 2/3 (0.67) in. for 3/8-(0.37-)in. rods. Apparently only an approximation of rod size can be expected when investigating multiple rod systems.

Quality check of steel rods

13. In order to evaluate the ability of the instrument to detect differences in the quality of rods, two rods of identical diameter (0.63 in.) but different strengths were used. A 7/8-in. wood spacer inserted between the high-strength rod (85,000 psi) and the probe resulted in a deflection reading of 57 (range 0 to 90) on the outer scale in the retro-range of the galvanometer. An intermediate grade steel rod (68,000 psi) yielded a reading of 79. Thus the 17,000-psi difference in ultimate strength of the two rods resulted in a difference of 22 units in the deflection readings. It can, therefore, be concluded that the instrument could be used to secure relative estimates of the quality of steel rods. However, it is necessary that the spacing of the rods allow operation in the retrorange of the galvanometer.

Applications not evaluated

14. The manufacturer's literature listed several additional uses of the device which were not evaluated in this investigation. These included (a) locating and identifying reinforcing steel in complex reinforcement systems, i.e. different size rods at various depths oriented in two or more directions, (b) quality (degree of corrosion) checking of embedded reinforcing rods, and (c) determining the location of heating pipes and other ferromagnetic items.

Conclusions

15. Based on this limited investigation, the following conclusions seem warranted:

a. Location, i.e. alignment and lateral positioning, of rein-
forcing rods can be determined with the instrument tested
in this study if rods are embedded not more than 4-1/2 in.
and spaced not less than 2 in. apart.

b. Identification of different size rods is possible but re-
quires careful, particular work. Tests indicated that the
instrument can be used to approximately identify rods up
to 1 in. in diameter with a maximum cover of 2 in. Correct
identification of rods over 1 in. in diameter or embedded
more than 2 in. is difficult.

c. If the rod diameter is known, either from plans or as
previously determined by tests, the thickness of concrete
covering can be approximately determined to an accuracy
of 1/4 in. for covering up to 4 in.

d. An approximation of rod size can be secured when investi-
gating multiple rod systems.

e. The instrument can be used to secure relative estimates of
the quality of steel rods if the rod spacing allows opera-
tion in the retrorange of the galvanometer.

f. Good judgment and intelligence on the operator's part are
essential to a proper evaluation with the device. Any
information from plans, drawings, or specifications con-
cerning the reinforcing relative to the structure under
investigation would be useful in an evaluation with the
device.

g. Apparently, when precise information on both size of rod
and thickness of cover is desired, the simplest procedure
is to use the instrument to locate the rod approximately
and then remove surface concrete down to the steel for the
precise measurements.

Appendix A: Evaluation of Instrument B

1.   Subsequent to the completion of the investigation of instrument A, a somewhat similar apparatus, designated instrument B, was evaluated. In-strument B, shown in fig. A1, operates on much the same principle as
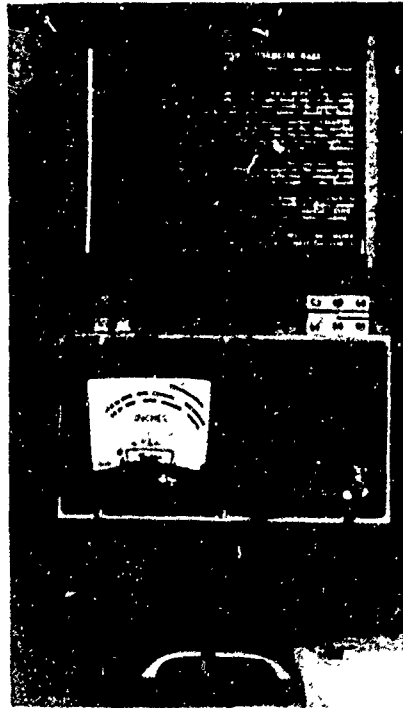
Fig. A1.   Instrument B

instrument A.   However, instrument B will only locate reinforcing steel; it will not identify the size of the located rods.   The manufacturer's litera-ture claimed that the apparatus is capable of determining orientation of reinforcing rods and amount of concrete coverage up to 3-in. cover.   Two scales are available on the dial face of the instrument: scale A for 0 to 1-1/4 in. of cover, and scale B for 1 to 3 in. of cover.   The instrument weighs 6-1/4 lb and costs approximately $200.

2.   Tests were made on the blocks shown in fig. 1, page 3 of the main text to evaluate the apparatus.   Calibration had been accomplished by the manufacturer.   It was discovered that by scanning the surface with the probe axis, orientation of reinforcing rods could be determined in much the same manner as with instrument A.   Results of tests with instrument B to

determine concrete cover are given below:

Concrete Cover, in.

Indicated	Actual	Rod Size, in.	Scale
1/2	1/2	1-3/8	A
7/8	1	1	A
1-1/4	1-1/2	1/2	A
1-1/2	1-3/4	3/8	B
1-7/8	2-1/8	1-3/8	B
2-1/2	2-5/8	1	B
3	3-1/8	1/2	B
3	3-1/4	3/8	B

3. Indications are that the thickness of concrete covering can be approximately determined to an accuracy of 1/4 in. for coverings up to 3 in. Determinations are apparently unaffected by rod size. Thus, instrument B is comparable to instrument A as a cover indicator; however, instrument A requires a knowledge of rod size and instrument B does not. Therefore, it would seem practical to use instrument A when information on rod size and amount of cover are desired and instrument B when only the thickness of concrete covering (up to 3 in.) is desired.